ABSTRACT

This thesis presents the implementation of the upper bound limit analysis in combination with finite elements and linear optimization for solving different stability problems in geomechanics under plane strain conditions. Although the nonlinear optimization techniques are becoming quite popular, the linear optimization has been adopted due to its simplicity in implementation and ease in attaining the convergence while performing the analysis. The objectives of the present research work are (i) to reduce the computational effort while using an upper bound finite element limit analysis with linear programming in dealing with geotechnical stability problems, and (ii) to obtain solutions for a few important geotechnical stability problems associated with reinforced earth, unsupported tunnels and a group of anchors. It is also intended to examine the developments of the failure patterns in all the cases.

For carrying out the analysis for different stability problems, three noded triangular elements have been used throughout the thesis. The nodal velocities are treated as basic unknown variables and the velocity discontinuities are employed along the interfaces of all the elements. The soil mass is assumed to obey the Mohr-Coulomb's failure criterion and an associated flow rule. The Mohr-Coulomb yield surface is linearized by means of an exterior regular polygon circumscribing the actual yield circle so that the finite element formulation leads to a linear programming problem.

A simple technique has been proposed for reducing the computational effort while solving any geotechnical stability problem by using the upper bound finite element limit analysis and linear optimization. In the proposed method, the problem domain has been discretized into a number of different regions in which a particular order (number of sides) of the polygon has been specified to linearize the Mohr-Coulomb yield criterion. A greater order of the polygon needs to be chosen only in that part of the domain wherein the rate of the plastic strains becomes higher. The computational effort required to solve the problem with this implementation reduces considerably. By using the proposed method, the bearing capacity has been computed for smooth as well as rough strip footings and the results obtained are found to be quite satisfactory.

The ultimate bearing capacity of a rigid strip footing placed over granular, cohesive-frictional and purely cohesive soils, reinforced with single and a group of two horizontal layers of reinforcements has been determined. The necessary formulation has been introduced to incorporate the inclusion of reinforcement in the analysis. The efficiency factors, η_c and η_γ, to be multiplied with N_c and N_γ, for finding the bearing capacity of reinforced foundations, have been established. The results have been obtained (i) for different values of soil friction angles in case of granular and cohesive-frictional soils, and (ii) for different rates at which the cohesion increases with depth for purely cohesive soil under undrained condition. The optimum positions of the reinforcements' layers corresponding to which η_c and η_γ becomes maximum, have been established. The effect of the length of the reinforcements on the results has also been analyzed. As compared to cohesive soil, the granular soils, especially with greater values of frictional angle, cause much more predominant increase in the bearing capacity.

The stability of a long open vertical trench laid in a fully cohesive and cohesive-frictional soil has been determined with an inclusion of single and a group of two layers of horizontal reinforcements. For different positions of the reinforcement layers, the efficiency factor (η_s), has been determined for several combinations of *H/B*, *m* and ϕ; where *H* and *B* refer to height and width of the trench, respectively, and *m* accounts for the rate at which the cohesion increases linearly with depth for a fully cohesive soil with ϕ = 0. The effect of height to width of the long vertical trench on the stability number has been examined for both unreinforced and reinforced soils. The optimal positions of the reinforcements layers, corresponding to which η_s becomes maximum, have been established. The required length of reinforcements to achieve maximum efficiency factor corresponding to optimum depth of reinforcement has also been determined. The magnitude of the maximum efficiency factor increases continuously with an increase in both m and ϕ.

The effect of pseudo-static horizontal earthquake body forces on the stability of a long unsupported circular tunnel (opening) formed in a cohesive frictional soil has been determined. The stability numbers have been obtained for various values of H/D (H = tunnel cover, D = diameter of the tunnel), internal friction angle (ϕ) of soil, and the horizontal earthquake acceleration coefficient (α_h). The computations revealed that the values of the stability numbers (i) decreases quite significantly with an increase in α_h, and (ii) become continuously higher for greater values of H/D and ϕ. The failure patterns have also been drawn for different combinations of H/D, ϕ and α_h. The geometry of the failure zone around the periphery of the tunnel becomes always asymmetrical with an inclusion of horizontal seismic body forces.

The interference effect on the stability of two closely spaced parallel (twin) long unsupported circular tunnels formed in fully cohesive and cohesive-frictional soils has been evaluated. The variation of the stability number with S/D has been established for different combinations of H/D, m and ϕ; where D refers to the diameter of each tunnel, S is the clear spacing between the tunnels, and ϕ is the internal friction angle of soil and m accounts for the rate at which the cohesion increases linearly with depth for a soil with $\phi = 0$. On account of the interference of two tunnels, the stability number reduces continuously with a decrease in the spacing between the tunnels. The minimum spacing between the two tunnels required to eliminate the interference effect increases with (i) an increase in H/D and (ii) a decrease in the values of both m and ϕ. The failure patterns have also been generated for a few cases with different values of S/D. The size of the failure zone is found to become smaller for greater values of m and ϕ.

The horizontal pullout capacity of a group of two vertical strip anchors embedded, along the same vertical plane in sand, at shallow depths has been determined. At collapse, it is assumed that the anchor plates are subjected to the same uniform horizontal velocity without any bending or tilt. The pullout resistance increases invariably with increases in the values of embedment ratio, friction angle of the sand mass and anchor-soil interface friction angle. The effect of spacing (S) between the anchors on their group collapse load is examined in detail. For a given embedment ratio, the total group failure load becomes maximum corresponding to a certain optimal spacing (S_{opt}). The values of S_{opt} increases with an increase in the value of ϕ, but the changes in the value of H/B and δ/ϕ do not have any significant effect on S_{opt}.

The vertical uplift capacity of a group of two horizontal strip plate anchors with the common vertical axis buried in purely cohesive as well as in cohesive frictional soil has been computed. The variation of the uplift factors F_c, F_q and F_γ, due to the contributions of soil cohesion, surcharge pressure and unit weight, respectively, has been evaluated for different combinations of S/B and H/B. As compared to a single isolated anchor, the group of two anchors generates significantly greater magnitude of F_c. On the other hand, the factors F_q and F_γ, for a group of two anchors are found to become almost equal to that of a single isolated anchor as long as the levels of the lower plate in the group and the single isolated anchor are kept the same. For the group of two horizontal strip plate anchors in purely cohesive soil, an increase of cohesion of soil mass with depth and the effect of self weight of the soil have been incorporated. The uplift factor $F_{c\gamma}$ both due to cohesion and unit weight of the soil has also been computed for the anchors embedded in clay under undrained condition. For given embedment ratios, the factor $F_{c\gamma}$ increases linearly with an increase in the normalized unit weight of soil mass ($\gamma H/c$) upto a certain value before attaining a certain maximum magnitude.

The computational results obtained for different research problems would be useful for design.